Applied antineutrino physics

Patrick Huber

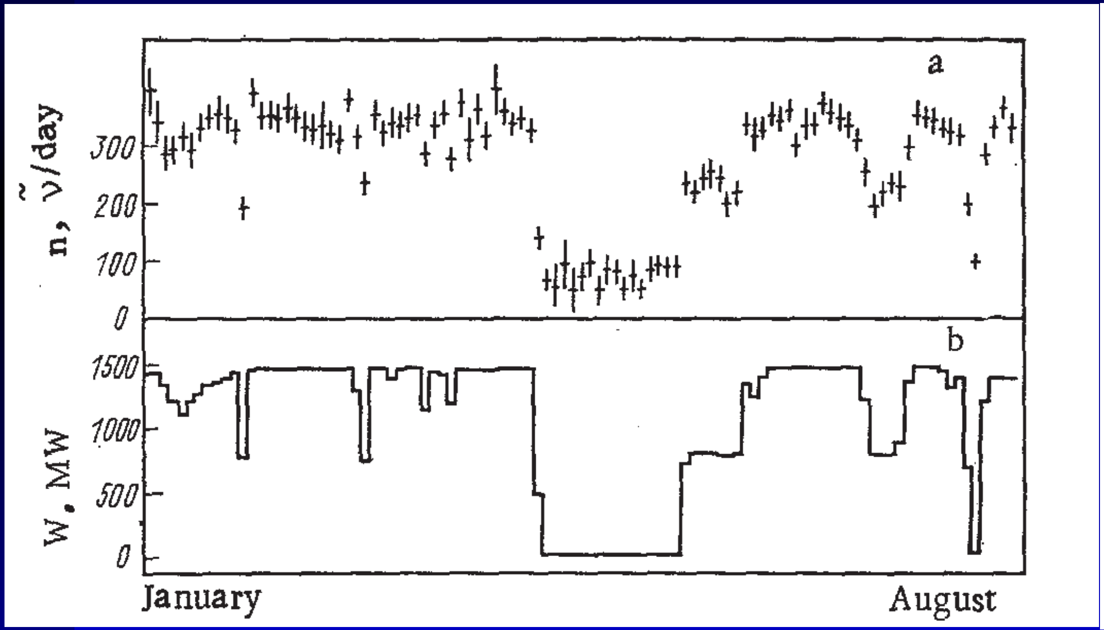
Center for Neutrino Physics – Virginia Tech

Workshop on the Intermediate Neutrino Program
Brookhaven National Laboratory, Upton, NY
February 4 – 6, 2015

Reactor monitoring

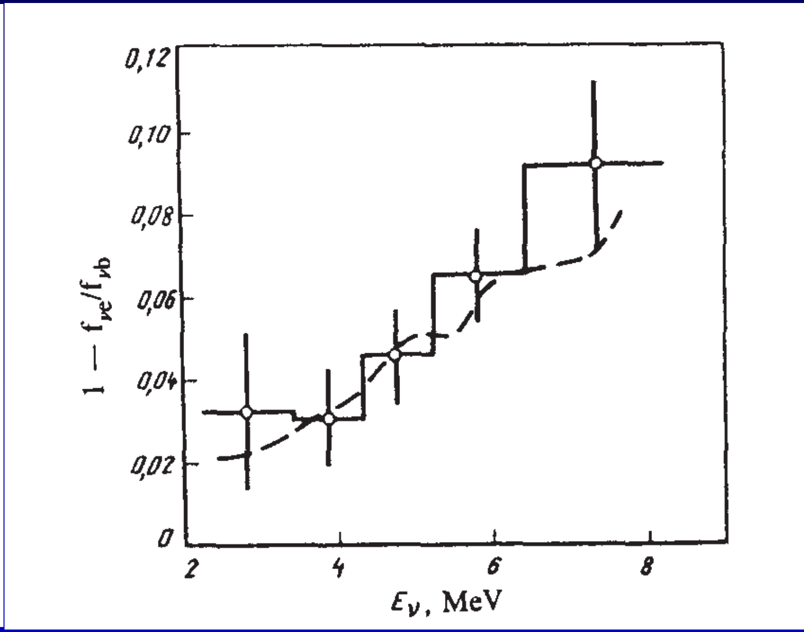
Pioneering work by a group at the Kurchatov institute

Power monitoring



Korovkin *et al.*, 1988

Fuel burn-up



Klimov *et al.*, 1994

In the U.S. there as been ongoing work over the past decade at LLNL and Sandia sponsored by the NNSA, notably SONGS

The standard detector

4.3E29 target protons

10-20 metric tonne actual detector weight

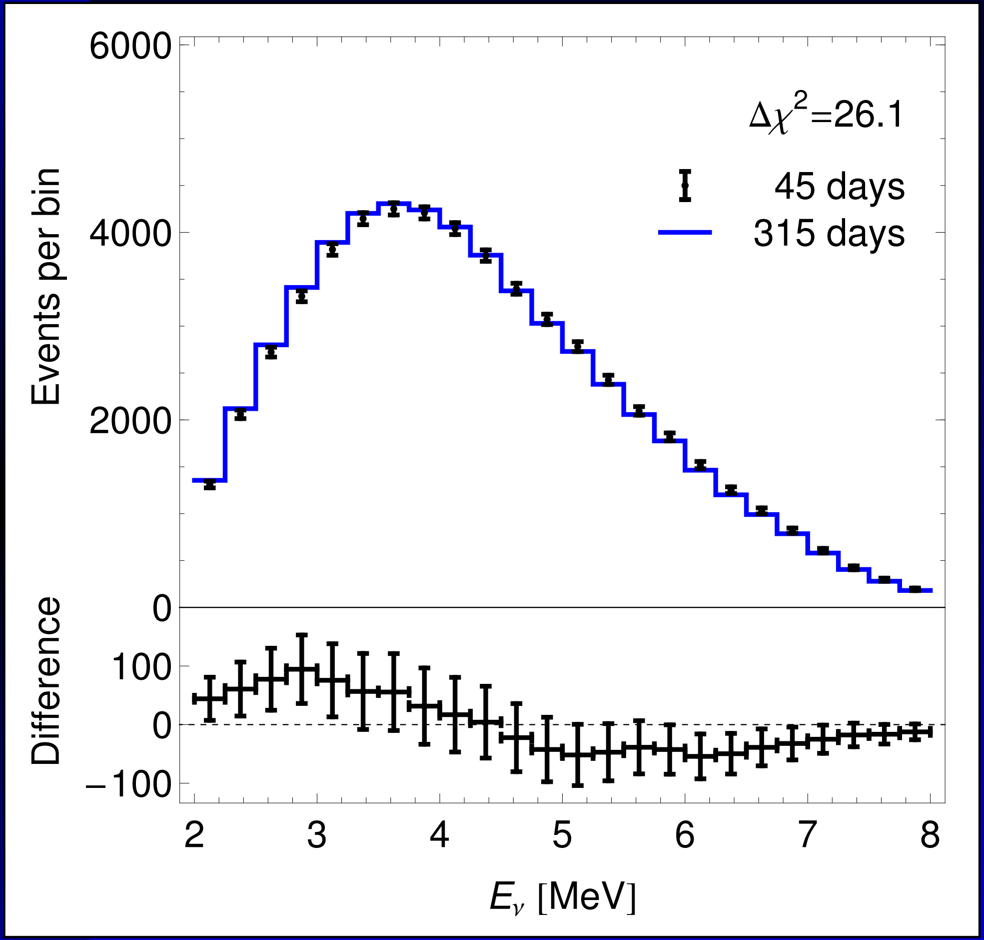
No overburden

Irreducible cosmogenic background

Detector mass depends on material and efficiency

Efficiency [%]	25	40	60	80
Liquid scintillator	20.1	12.5	8.4	6.3
Solid scintillator	$\boxed{34.0}$	21.3	14.2	10.6

Exploiting the energy spectrum



Christensen, Huber, Jaffke, Shea, 2014

Comparing a reactor core at 45 days in the cycle to the same core at 315 days in the cycle

The later spectrum is indeed much softer and the difference is more than 5 σ

Corresponding to a difference in plutonium content of about 7 kg

Diversion

Considering a diversion of plutonium from a known reactor, two separate problems have to be addressed

- the amount of plutonium produced – requires a continuous power history from antineutrinos or otherwise
- the amount of plutonium in the reactor core – can be measured ad-hoc using antineutrinos or by careful analysis of discharged fuel

A mismatch between these two quantities is indicative of a diversion.

Iran – 2014

Arak – 40MW$_{th}$ heavy water moderated, natural uranium fueled reactor

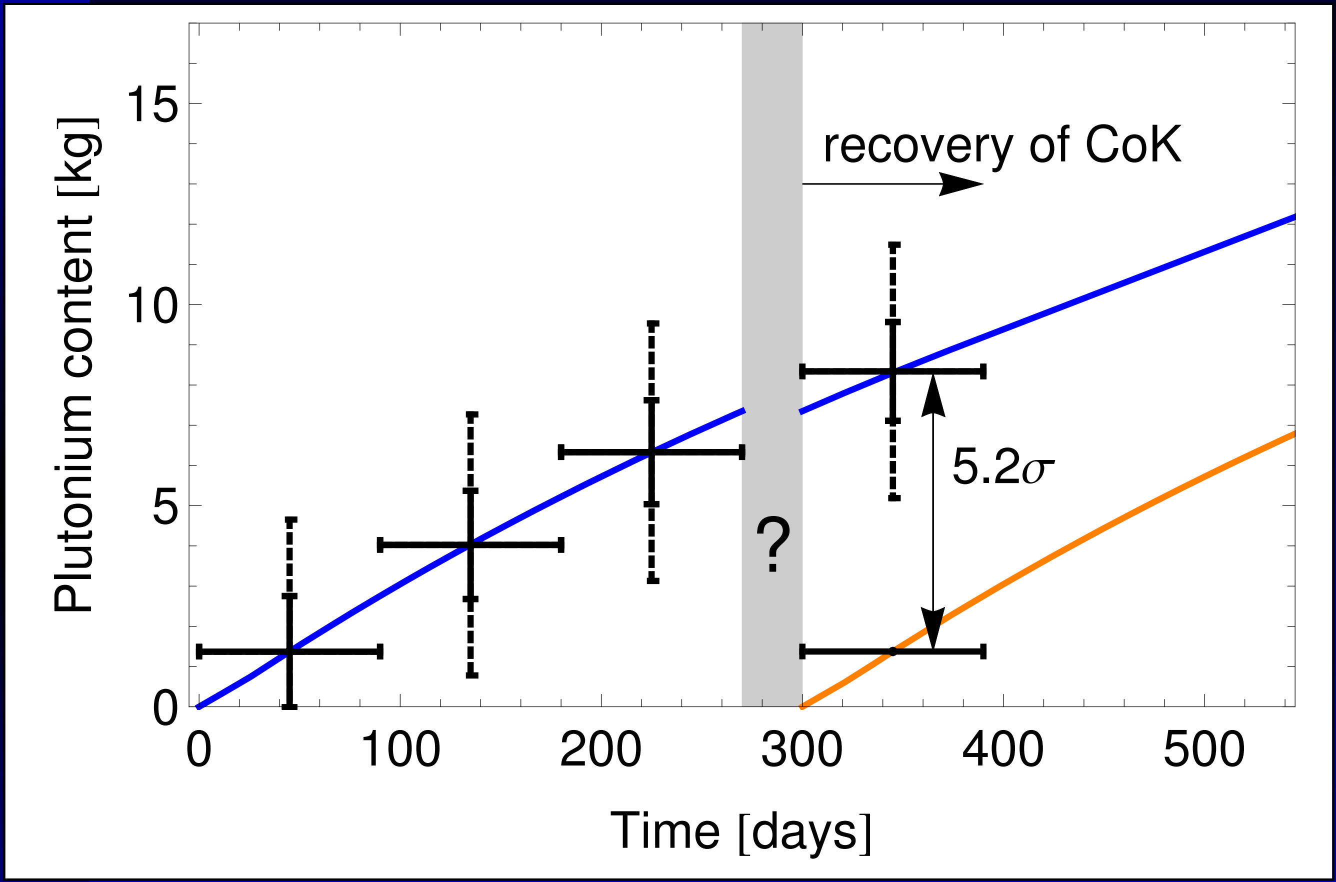
Once operational, produces 10 kg weapons-usable plutonium per year

The Nth month scenario

- Full inspector access for N-1 month
- Reactor shutdown in the Nth month
- Loss of the continuity of knowledge in the Nth month

Reasons could range from technical glitch over diplomatic tensions to full scale diversion – finding out which one is the true one can make the difference between peace and war.

Iran – results



Christensen, Huber, Jaffke, Shea, 2014

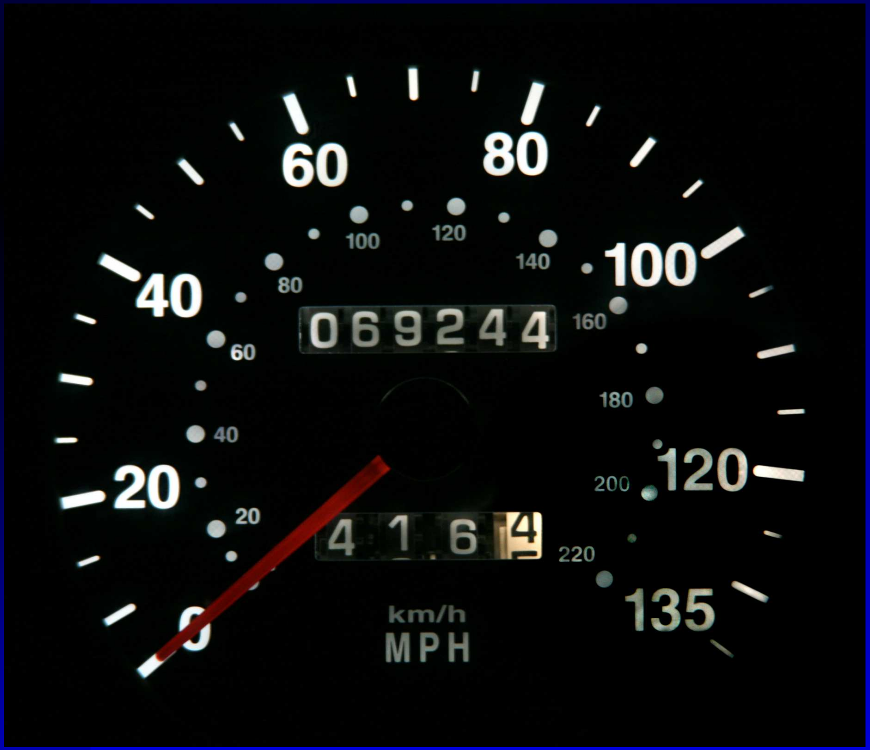
270 days corresponds to 93% plutonium-239

1.2 kg plutonium sensitivity

An undeclared refueling can be detected with 90% confidence level within 7 days.

Automobile analogy

speed	thermal power
trip mileage	burn-up
used gas	produced plutonium



requires continuous speed measurement, discrepancies show up at refueling only

snapshot of used gas without prior record, discrepancies show up as you drive

Summary

Antineutrino reactor monitoring at close range, as part of cooperative safeguards, can provide near real time plutonium content measurements (think fuel gauge in a car).

Practical challenges are

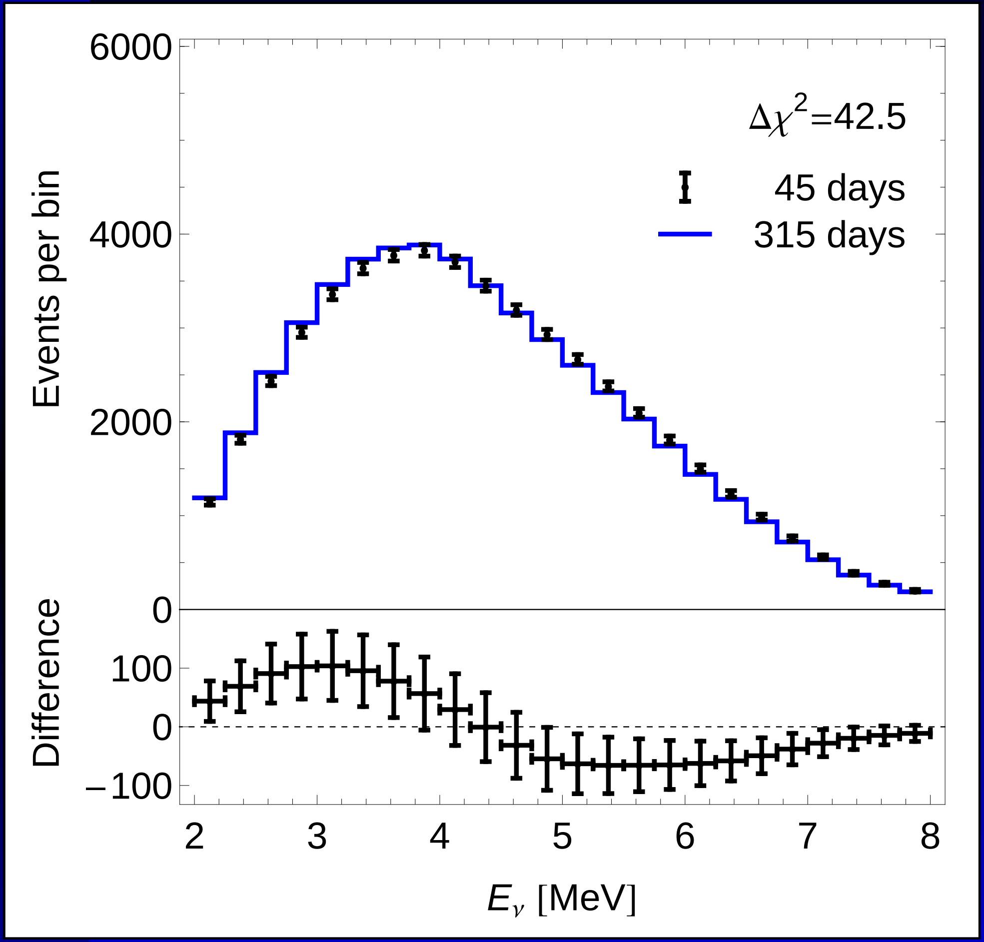
- detectors with very good background rejection with reasonable energy resolution
- understanding of neutrino emissions

and both these challenges are faced by short-baseline reactor experiments and safeguards applications – a true synergy between applied and basic research.

“I don’t say that the neutrino is going to be a practical thing, but it has been a time-honored pattern that science leads, and then technology comes along, and then, put together, these things make an enormous difference in how we live” – Frederick Reines

Backup slides

What about the bump?

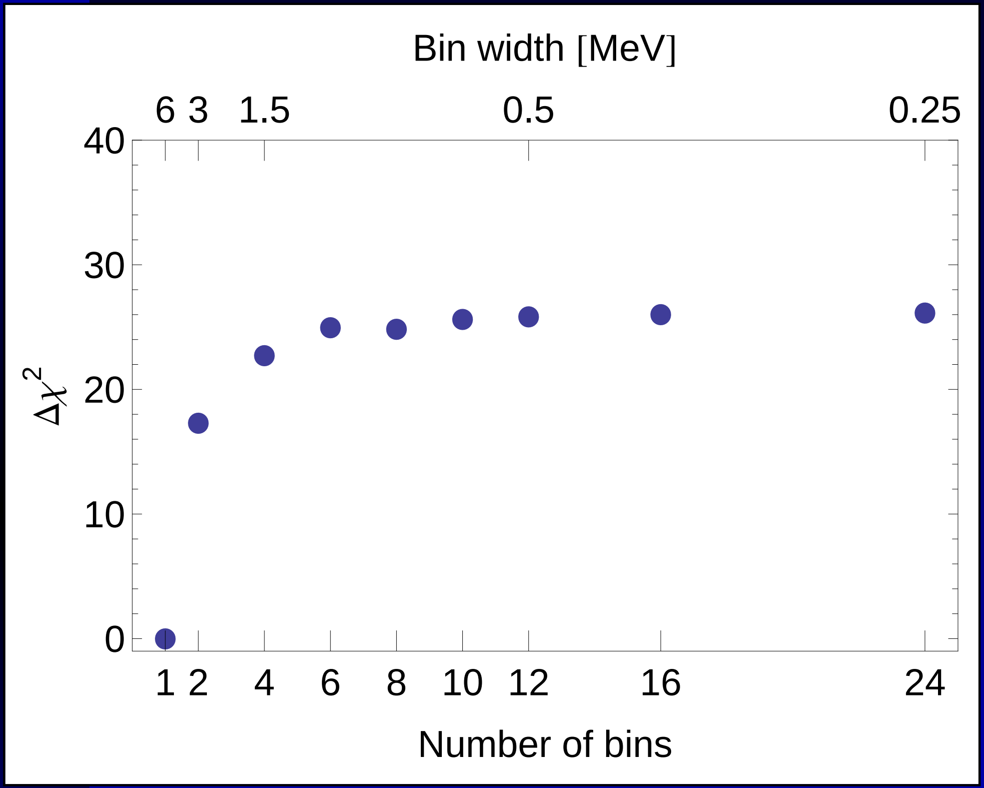


Same as before, but with Dwyer and Langford, 2014 antineutrino yields.

This would improve sensitivity by 30%

Clearly, accurate measurements of antineutrino yields from various reactors are a necessary input – see for instance PROSPECT

How much resolution is needed?



Statistical power is flat for bins smaller than 1 MeV

Even with only 2 bins, 2/3 of statistical power achieved

For comparison, the Daya Bay detectors have a resolution of about 0.65 MeV at an energy of 4 MeV
Daya Bay, 2013